Precision Cosmology: Constraining the Mass Function and Bias of Dark Matter Halos

Michael S. Warren, Gerard Jungman, and Daniel Holz (T-6); Salman Habib, Kevork Abazajian, and Luis Teodoro (T-8); Katrin Heitmann (ISR-1); and Uroš Seljak (Princeton University);
mswarren@lanl.gov

Obtaining a quantitative understanding of galaxy formation and clustering is the most important open theoretical problem in the study of the large-scale structure of the universe. Observations strongly support the theoretical paradigm that structure evolves through gravitational collapse of primarily dark matter. However, the fundamental problem of associating individual, luminous galaxies with features in the dark matter density distribution remains. Connecting the fundamental theories of the universe with the flood of observational data can only be accomplished with numerical experiments such as those we are performing. The overall objective of our project is to obtain a quantitatively precise understanding of gravitational clustering from the largest to the smallest scales accessible to observations via direct N-body simulation. During the past year, we have performed a series of about 10 high-resolution simulations with over one billion particles in each to address some of these fundamental questions.

On large scales, galaxies and their halos are usually assumed to trace the dark matter

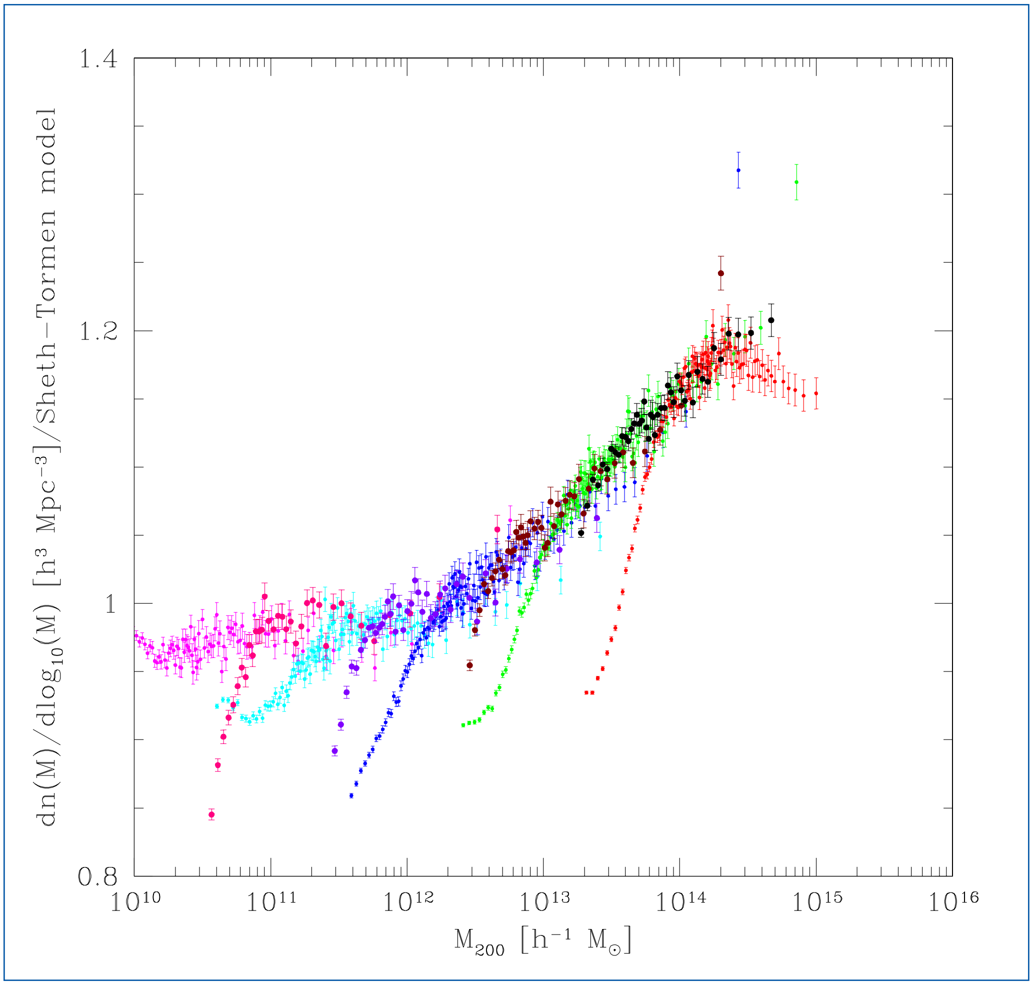

Figure 1— ***The mass function from a series of 1024^3 simulations.***

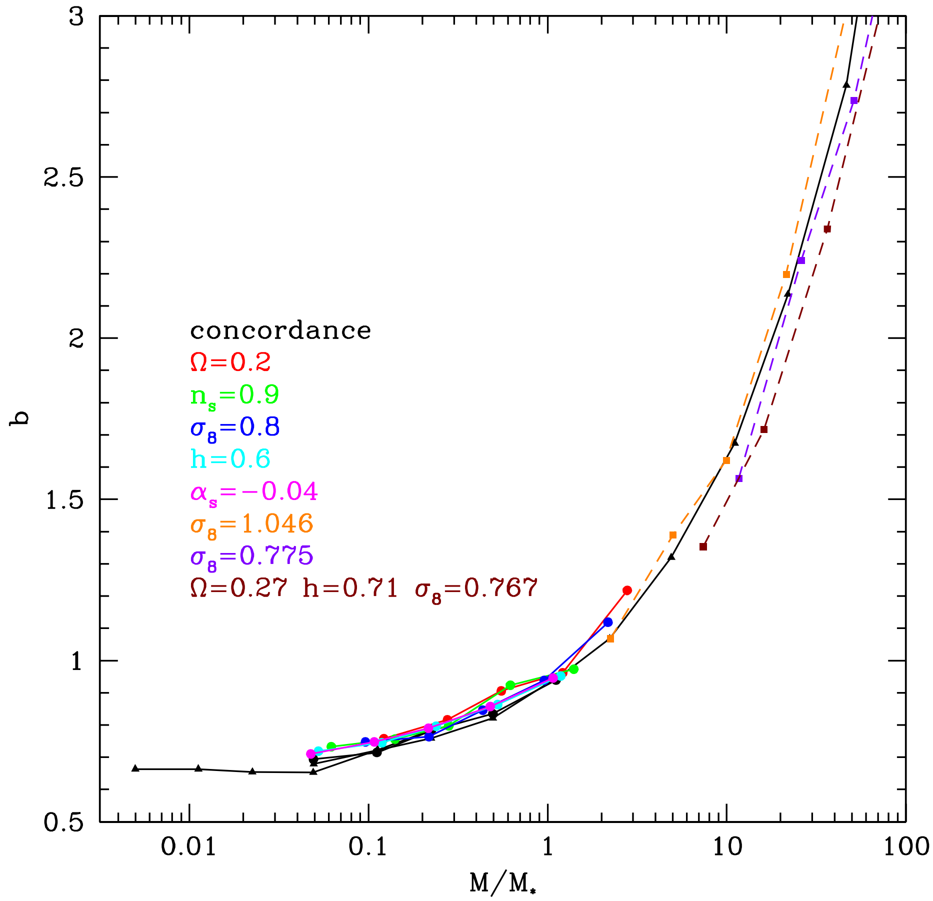

Figure 2— Bias as a function of nonlinear mass for a variety of cosmological models.

with a constant bias, and dark matter is assumed to trace the linear density field. We test these assumptions using large N-body simulations, which can both resolve the small galactic-size halos and sample the large-scale fluctuations. We explore the average halo bias relation as a function of halo mass and show that existing fitting formulae overestimate the halo bias by up to 20% in the regime just below the nonlinear mass. We propose a new expression that fits our simulations well. We find that the halo bias is nearly constant, b~0.65–0.7, for masses below one tenth of the nonlinear mass. We also explore the relation between the initial and final dark matter in individual Fourier modes and show that there are significant fluctuations in their ratio, ranging from 10% rms at k~0.03h/Mpc to 50% rms at k~0.1h/Mpc. We argue that these large fluctuations are caused by perturbative effects beyond the linear theory, which are dominated by long wavelength modes with large random fluctuations. Similar or larger fluctuations exist between halos and dark matter and between halos of different mass. While these fluctuations are small compared to the sampling variance, they are significant for attempts to determine the bias by relating directly the maps of galaxies and dark matter or the maps of different galaxy populations, which would otherwise be immune to sampling variance.